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A review on the role of soil microbial biomass in eco-restoration of degraded ecosystem with special reference to mining areas

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Abstract: Soil microbial biomass constitutes a transformation matrix for all the natural organic material in the soil and acts as labile reservoir of plant available nutrients. In general plants serve as carbon source for the microbial community and in turn microbes provide nutrients for growth through mineralization of plant and animal residues, and organic matter, thus soil microbial biomass is a significant parameter to draw an inference about the soil health. Biodiversity of visible plants and animals has received a greater attention than the meso or micro level organisms. Information about soil microbial biomass can help to quantify the extant of degradation and may help to provide the effective methodology for the restoration in the degraded terrestrial ecosystems. As the changing global climate has been one of the major environmental challenges facing the world today, there is an increasing need to restore the degraded ecosystem, increase their productivity, to increase the carbon sequestration potential of such areas and to make them suitable for the sustainable forestry purposes. This review provides the importance of soil microbial biomass in the derelict mined ecosystems and suggests that an increase in microbial biomass in the soil may enhance the soil fertility, and provide an effective substrate for the nutrient mineralization.

Keywords: Microbial biomass, Restoration, Degradation, Soil health

INTRODUCTION

The earth is a complex set of systems viz. physical, chemical, biological, hydrology and geology. Each and every building block contributes in the spontaneity of the earth. Likewise the basic micro-counterpart plays a significant role in the terrestrial ecosystems. Micro organisms are ubiquitous in the environment, where they have a variety of essential functions to play. Micro organisms are so small in size and that many of them are capable of growing on a variety of environment, they are found universally distributed in nature. They live almost everywhere on the earth where there is water, hot springs on the ocean floor and deep inside rocks within the earth's crust (Jha and Singh, 1992; Kumar *et al.,* 2009). Thus being a vital fraction of soil organic matter, microbes act as a source and sink of nutrients and play critical role in nutrient conservation in dry tropical environment (Singh *et al.,* 1989). Ecosystem can be characterized in terms of their structure (biota and physical environment) and processes (transfer of energy and material between organism and the physical environment) (Chapin *et al.,* 2002).

Microbial biomass is both the agent of biochemical changes in soil and a repository of plant nutrients that are more labile than the bulk of soil organic matter (Patra, 1994). The level of soil microbial biomass and the activity of top soil organisms are important factor in determining the soil health. From the view of soil productivity the soil microbial biomass controls the major processes involved in nutrient transformation and cycling soil organic matter maintenance and macro aggregation for favourable water and aeration characteristics. Values of microbial biomass can provide one of the most satisfactory estimates of the restoration of degraded lands. In terms of ecosystem stability, microbial biomass may be the most essential part for terrestrial ecosystem.

Since early 1970's there have been receiving ever more attention for quantification of soil microbial biomass. It has several reasons firstly microbes have a spatial heterogeneity and secondly it is difficult of characterize microbes due to taxonomic ambiguity. The soil microbial diversity varies according to pH, soil moisture, and organic matter content, floral composition, and climatic conditions. Further microbes have less ability to be cultured and molecular based methodologies have some limitations. It had been felt that there was a strong need to collect the information about the soil health. Therefore after development of quantification of the methodology for soil microbial biomass it was possible to overtake all the limitations regarding soil biological attribute.

Microorganisms play all important role in regulating ecosystem processes ranging from nutrient mineralization and cycling, to soil carbon storage, trace gas fluxes, transformation of aqueous solutes and processing of water pollutants (Mooney *et al.,* 1987, Holden and Firestone 1997, Schlesinger 1997, Groffman and Bohlen, 1998), and for driving above ground ecosystem (Van der Heijden *et al.*, 1998; Cairney, 2000; Klironomos *et al.,* 2000; Ovreas, 2000).

In a balanced soil, plants grow in an active and vibrant environment. The mineral content of the soil and its physical structure are important for their well-being, but it is the life in the earth that powers its cycles and provides its fertility. The soil biota includes vast numbers of microorganisms that naturally reside in soil and perform a wide range of functions which are essential for a normal and healthy soil. Soil microbes decompose organic matter, release nutrients into plant available forms moreover soil microbial community also regulates the production and destruction of environmental pollutant such as nitrous oxides, methane, nitrates and other biologically toxic compounds (Doran *et al.,* 1993) and degrade toxic residues. Microbes act as antagonists to pathogens, influence the weathering and solubilization of minerals and contribute to soil structure and aggregation. They also form the symbiotic associations with roots. Without the activities of soil organisms, organic materials would accumulate and litter the soil surface, and there would be no food for plants that is why all organisms in the biosphere depend on microbial activity (Pace, 1997). While many anthropogenic activities, such as city development, agriculture, mining, use of pesticides and pollution can potentially affect soil microbial diversity, it is unknown how changes in microbial diversity can influence below-ground and above-ground ecosystems.

MICROBIAL BIOMASS

The soil microbial biomass is the eye of the needle through which all natural organic materials that enter the soil must pass, often more than once as they degraded to the organic compounds from which they came (Patra, 1994). The soil microbial population consisting of bacteria, fungi and microfauna(Micro means microscopic that one can't see with naked eyes and fauna means animals) are termed as soil microbial biomass (SMB). This pool is closely related to the soil organic matter (SOM) pool (Jenkinson and Ladd, 1981, Anderson and Domsch, 1989; Smith and Paul, 1990) and is measures as the amount of C and N in the SMB thus the terms SMB-C and SMB-N. Soil microbial biomass is a vital soil component, acting as a source and a sink for plant available nutrients, as well as catalyzing the transformations of these nutrients in soil. During decomposition the SMB assimilates complex organic substrates for energy and biomass carbon with excess inorganic nutrients being released to the soil. Microbial biomass represents a relatively small standing stock of nutrients, compared to soil organic matter; hence microbial biomass is defined as living component of soil organic matter (Jenkinson and Ladd, 1981) excluding macro fauna and roots of plants. Soil microbial biomass (SMB) values reported in the literature vary by greater than an order of magnitude ranging from 110 kg- C/ ha in a cultivated field with total C of 0.7% to 2240 kg- C/ ha in a grassland soil with total C 7.0% (Smith and Paul, 1990). SMB-N value range from 40- 400 kg N/ ha based on 23 published reports from 13 countries. Global averages for SMB-C are 700, 1090, 850 for cultivated, grassland and forest soils respectively. For SMB-N the values are 195, 225 and 170 for cultivated, grassland and forest soils respectively. The proposed typical methods of determination are by fumigation-incubation, fumigation-extraction and substrate- induced respiration methods (Ross and Sparling, 1993). On the basis of detailed analysis, it is reasonable that future research would be focused on the impact of land use change on soil microbial biomass in tropical and subtropical ecosystems (Zhang Jiang-shan *et al.,* 2005).

The ultimate goal of this kind of reclamation is to restore a stable and productive forest ecosystem. This goal can be achieved only if soil functionality is restored.

MICROBIAL BIOMASS AND SOIL ORGANIC CARBON IN DIFFERENT LAND USES ACROSS THE GLOBE

The principal players in the decomposition process are the microbial population, i.e., the bacteria, fungi and viruses. Although the quantification of soil microbes is difficult because of variety of reasons yet various scientists quantify the microbes in a cumulative form i.e. microbial biomass in different land uses and plantation (Table 1). As a very broad generalization, the amount of microbial biomass in a soil reflects the total organic matter content, with the living component forming a low proportion of total (Sparling, 1997).

Data presented in table -1 reveals the relationship between the soil organic carbon with soil microbial biomass. The conversion of forest into other land uses resulted in remarkable decline in the amounts of soil nutrients and soil microbial biomass. In dry tropical environment the microbial biomass proved to sensitive indicator of land use change (Srivastava and Singh, 1991). Singh *et al.,* (1989) find a reciprocal relation between microbial biomass and plant growth rate, hence concluded that soil microbial biomass act as sink and source of nutrient in the dry tropical environment and suggest that microbial immobilization may be a main source of nutrients for plant that may lead to nutrient conservation. If we consider the function of soil microbial biomass; it is to accumulate and conserve nutrients in a biologically active form during the dry period (high biomass, low turnover), when the activity of the plants is low and they are not able to extract nutrients effectively from soil, and then to release them rapidly during the monsoon period (low biomass, high turnover). The role of the microbial fraction in mediating soil processes, and their relatively high rate of turnover, logically suggest that the microbial fraction could be a sensitive indicator and early predictor of other changing soil organic matter (Jenkinson and ladd, 1981; Stout *et al.*, 1981; O'Brien, 1984; Jenkinson, 1990). There is increasing evidence the microbial biomass and biochemical parameters such as enzyme activity and labile organic matter are used to be the sensitive indicators of ecology stress suffered by a soil and its recovery (Dick, 1997) vegetation cover can have profound effects on soil properties (Rutigliano *et al.,* 2004; Singh *et al.,* 2004), mainly due to its contribution towards inputting the amount of organic matter to soil by applying carbon and energy sources from root exudates and remaining of plants. Soil microbial biomass is relative not only to the quantity , but also to the quality of soil organic matter (Jia *et al.* 2005) which indicates that there should be emphasis to select the plant species which can improve the soil organic matter. In general plants serve as a carbon source for microbial community and in turn microbes provide nutrients for plant growth through mineralization of plant and animal residues and soil organic matter (Srivastava and Singh, 1991). Information of microbial biomass can help in restoration of degraded mine lands, spoil and overburden dumps. Plantation of *Caragana micropylla* Lam., along a chronosequence in sandy land reveals a relative increase in soil microbial biomass C and N (Cao *et al.,* 2008). An effective plantation rehabilitation measure can provide the satisfactory estimate of soil microbial biomass, in this context finding of Chodak *et al.,* 2009., support that the reclamation measures boost the gross microbial properties as well as it promote the rapid development of metabolic abilities characteristic of natural forest soil microbial communities. The plantation enhanced the nutrient status of the degraded mine spoil land (Dutta *et al.,* 2002). Some studies of reclaimed soils of mined lands indicate that microbial community may take 20 years or longer to recover (Insam and Domsch, 1988; Sawada, 1996; Anderson *et al.,* 2002; Mummy *et al.,* 2002a, b). Findings of Shao-shan *et al.,* (2009) reveals significant impact of natural vegetation succession in overgrazed grassland on all the properties of surface soils, including the soil nutrients, organic matter, soil microbial biomass, respiration and enzyme activities. Microbial biomass reflects the degree of immobilization of carbon and nitrogen. A decrease in soil microbial biomass could result in mineralization of nutrients, while an increase in microbial biomass may leads to immobilization of nutrients (McGill *et al.,* 1986). It was in agreement with Arunachalam and Pandey (2003); Jia *et al.,* (2005) that successional dynamics of MBC and MBN were linked to soil organic C and total N contents in the soil during secondary forest succession. Similar kind of findings support that Microbial biomass take a long time to recover in semi arid mine lands (Anderson, *et al.,* 2008) find out no significant difference among the reclaimed and undisturbed sites. Impact of inorganic fertilizer on soil microbial biomass was studied in a paddy field, and it was observed critically that soil microbial biomass is mainly correlated with soil organic carbon rather than P and N input to the soil (Zhong *et al.,* 2007), this study also contribute to the importance of soil organic carbon for the soil microbial biomass. Hence we can say that direct application of inorganic fertilizer to the areas of poor soil quality like degraded mine land, will not help to enhance the soil microbial biomass. It is therefore, suggested that to improve the soil quality ecological restoration scientist must have concern for the Soil organic carbon up gradation infect application of bio-fertilizer can help to cope with the problem associated with the degraded areas. Selection of suitable plant species also contributes to increase the soil organic carbon. Large pool of mineralizable organic matter can produce large amount of NH_4^+ via net mineralization (Finzi *et al.,* 1998), the fact favours the significance of soil organic matter. Seasonal changes and soil moisture impact studies on soil microbial biomass were done in different land use by Srivastava, 1992, it was found that the soil microbial biomass were high in summer season whereas microbial biomass was low in the rainy season it is because of grazing of microbes by the soil fauna increase during the rainy season leads to the reduction in microbial biomass. In the rainy season in these soil populations of amoebae, flagellates, nematodes and microarthropods increase (Dash and Guru, 1980) which accelerates the faunal predation.

ROLE OF SOIL MICROBIAL BIOMASS IN ECOLOGICAL RESTORATION OF DEGRADED LANDS

At the early stages of ecosystem development soil act as a critical controlling component, without the natural processes of soil development ecosystem would remain in degraded condition. Hence soils are made up of four basic components minerals, air, water and organic matter. Soil is actually a natural medium in which microbes live, multiply and die. Soil once removed during open cast mining gets depleted in all the four very basic components. Organic matter, mineral nutrients and microbial nutrients decrease and drastically disturbed due to surface mining (Indorante *et al.,* 1981; Toy and Shay 1987; Srivastava *et al.,* 1989; Srivastava and Singh 1991; Soni and Rawat 2005) Mine spoil heaps are composed of coarse rocks due to the deep mining operation and mineral processing. These spoils are not suitable for both plant and microbial growth because of low organic matter content, unfavorable pH, drought arising from coarse texture or oxygen deficiency owing to compaction

Table 1. Soil microbial biomass in different land uses and plantations.

Land use/ plantation	Total C (%)	Microbial biomass (µg g^{-1} of soil)	Reference
Pine forest	0.53	121	Ross and Sparling (1993)
Pasture	2.53	659	Fiegl *et al* (1995)
Scrub	39.2	5236	Sparling and Searle (1993)
Barren ? 2 mm	0.64	58	Roser *et al* (1993)
Dwarf scrub	0.47	50-225	Sarig and Steinberger (1994)
Forest	2.18	609	Srivastava and Singh (1991)
Savanna	1.20	397	‘ ’
Cropfield	1.06	250	‘ ’
Mine spoil	NA*	332	‘ ’
Sporobolus marginatus plantation	0.32	39.04	Kaur *et al* (1998)
Mixed grass	0.37	49.95	‘ ’
Acasia nilotica	0.51	104.64	‘ ’
Vetiveria zizanioides	0.58	135.14	‘ ’
Desmostachya bipinnata	0.71	195.25	‘ ’

(Agarwal *et al.,* 1993). The other limiting factor for revegetation of mine spoil may be salinity, acidity, poor water holding capacity, inadequate supply of plant nutrients and accelerated rate of erosion (Jha and Singh, 1991). During restoration of mine spoils, it is necessary to establish and maintain a vegetation cover without the use of top soils or other bulky amendments (Rimmer *et al.,* 1982) To recover the fundamental functionality of the soil ecosystem it is requisite to make an effective strategy to catalyze the natural return of some of the basis for further restoration processes. The cycling of nutrients regulates the sustainability of any plant community. Keeping in view the fact, soil microbial biomass was well studied in the agricultural system and even up to some extent in forest ecosystem. The cycling of nutrients regulates the sustainability of any plant community without cycling, nutrients will be lost or immobilized and plant community will not be capable of regeneration. Destruction of soil properties causes reduced soil productivity. Mine spoil present very rigorous condition for both plants as well as microbial growth because of low nutrient contents, either coarse texture or compact structure (Dutta and Agarwal, 2000). A comparative study of effect of various plantations was done in coal mine spoil and was observed that microbial biomass C, N and P were highest in the plot of *Grevellia pteridifolia* as compared to *Cassia siamea* (Dutta and Agarwal, 2002). Soil functionality greatly depends on the microbial structure. But there is little known about the dynamics of microbial biomass in mine spoils and overburden dumps. An interesting and important fact is that very little is known about the functional diversity and metabolic abilities of microbial communities is spontaneously developing mine spoil (Chodak *et al.,* 2009). Ross *et al.,* (1990) suggested that in the initial stage of the soil restoration, rate of mineralization of soil organic matter is dependent on substrate supply and the size of microbial population. The ratios of microbial biomass C: total C (Insam and Domsch 1988) and respiration: microbial C (Insam and Haselwandter 1989) have been proposed as measures of the success of reclamation efforts (Ross *et al.,* 1990). Smith and Paul (1990) concluded that monitoring of changes in ratios of fungi to bacteria and in species diversity, biomass estimation could be a powerful method of prediction. (Moussa *et al.,* 2007) suggested that low vegetation abundance and the poor condition (degradation) was the prime determinant of the low soil microbial biomass. Same thing was concluded by (Barbhuiya *et al.,* 2008) that the soil microbial biomass and its activities are dependent on the quality, quantity and turnover of detrital organic matter in the forest floor. Soil microbial biomass is a potential source of plant nutrients, and higher level of soil microbial biomass is an indicator of soil fertility. Considering the importance of soil microbial biomass, we frustratingly feel that there must be extensive work with reference to the restored overburden dumps, mine spoils degraded and mine lands. Microbial biomass may provide the information about the restoration progress of the degraded areas. Several gross microbial properties such as the amount of soil microbial biomass, soil respiration rate and metabolic quotient (Grahm and Haynes, 2004; Frouz and Novakova, 2005; Sourkova *et al.,* 2005) have been used to assess soil development in reclaimed post mining lands. For various chronosequences of reclaimed mine soils a gradual increase of organic carbon and microbial biomass has been reported (Srivastava 1991; Ruzek *et al.,* 2001; Grahm and Haynes, 2004; Sourkova *et al.,* 2005). Increasing content of soil organic carbon and microbial biomass may result in increased functional diversity of soil microbial communities (Yan *et al.,* 2000) which increase the functionality and stability of soil ecosystems

(Degens *et al.,* 2001; Lynch *et al.,* 2004) Role of soil microbes in the establishment of biogeochemical cycles, for energy transfer and formation of soil is well known, but standard quantitative information is lacking for optimum level of soil microbial biomass which is requisite for the soil development in the degraded areas.

MEASURES TO ENHANCE SOIL MICROBIAL BIOMASS IN DEGRADED MINE LAND

Soil microbial biomass may be a proven component for ecological restoration in the tropical ecosystems. The quantification of soil microbial biomass has well attempted across the globe in various land uses. We felt that there must be cost effective method to enhance the soil microbial biomass in the degraded land without avoiding the basic ecological principles for the ecological restoration of the overburden dumps and mine spoils. Selection of suitable plant species must be specified for the working plan of restoration project that can enhance the soil organic carbon, having suitable rhizosphere for microbial growth. Floristically differences between ecosystems would produce litter with chemically distinct substrates that will differentially foster microbial growth (Myers *et al.*, 2001). Rhizosphere development must be considered because it is one of the intense activity zone in immediate vicinity of a root system plant roots release appreciable amounts of photo-assimilated C in to the rhizosphere zone (Whipps and Lynch, 1982 and Norton *et al.,* 1989). Use of bio-fertilizers can be a good microbial enhancer in the degraded mine lands, direct input or spray of bio-fertilizer and green manure increase the soil microbial biomass in the mine overburden dumps and spoils. Endemic grass species should be incorporated because these grass species have short life span and they can decomposed very fast after their death, hence they can contribute in the soil organic matter moreover use of appropriate grass species can provide mulching to the soil to reduce the moisture content from the soil. Moisture can be a limiting factor for soil microbial biomass. In stress condition many plants are unable to uptake the Phosphorous from the soil, mycorrhizae is an effective combination which make plant able to phosphorous uptake from the soil. Mycorrhizae are very crucial in various soil functionaries like production of humic compounds, decomposition of primary minerals, and production of organic “glue” that binds the soil particles into water-stable aggregates (Sutton *et al.,* 1976). Mycorrhizal mycelium makes up a large portion of soil microbial biomass, there are likely to be the soil fauna that eat these hyphae. Species which allow the mycorrhizal associations and nodule formation for the nitrogen fixing bacteria, must be selected for the restoration of degraded mine lands.

Conclusion

A number of resource extraction activities like mining practice leads to the significant degradation to the ecosystem. There is a need to make an effective working plan for the ecological restoration and firstly, three is a need of restoration of soil microbial properties. No single soil property is sufficient to evaluate the effect of anthropogenic or natural impacts on an ecosystem, because all methods are subjected to limitations. It is therefore suggested that the soil microbial biomass can provide a more sensitive measure of change than total organic matter content. Soil microbial biomass even gives the satisfactory answer in extreme climatic or environmental conditions. More emphasis should be given to soil organic carbon content by keeping its importance in microbial management. It is evident that the characterization of microbial activity is sufficiently sensitive to differentiate between the soil cover of various discard sites and could be used as complementary assessment criteria to determine the rehabilitation status of sites associated with discard mining material. It also seems that a trend could exist between the progress of rehabilitation and r- and K- strategic microorganisms, with r-strategists favouring new sites or sites under reclamation and K-strategists favouring more stable environments. Studies on soil microbial biomass holds potential as complementary criteria for evaluating rehabilitation progress on mine discard sites.

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